INVESTING IN BETTER OUTCOMES: THE IMPACT OF DAYLIGHT IN THE BUILT ENVIRONMENT

by

Ryan Shindler

A Thesis Submitted to the Faculty of the

COLLEGE OF ARCHITECTURE, PLANNING & LANDSCAPE ARCHITECTURE

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

2019

THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

As members of the Master's Committee, we certify that we have read the thesis prepared by Ryan Shindler, titled *Investing in Better Outcomes: The Impact of Daylight in the Built Environment* and recommend that it be accepted as fulfilling the dissertation requirement for the Master's Degree.

Altaf Engineer Date: May 7, 2019

Susannah Dickinson Date: May 6th 2019

Aletheia Ida Date: May 8, 2019

Esther Sternberg Date: May 3, 2019

Final approval and acceptance of this thesis is contingent upon the candidate's submission of the final copies of the thesis to the Graduate College.

I hereby certify that I have read this thesis prepared under my direction and recommend that it be accepted as fulfilling the Master's requirement.

Altaf Engineer Date: May 7, 2019
Master's Thesis Committee Chair
School of Architecture, CAPLA

DEDICATION

In loving memory of my mother, Karen Shindler. Her devoted, compassionate spirit will forever be of utmost inspiration to me.

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

This paper focuses on the value of research and evidence in the design process with a focus on daylighting. Daylight is utilized as an example of an environmental attribute of built spaces that can be optimized, and backed up with evidence and research supporting its positive human impact potential. The paper explores and discusses the dynamic value of daylight in the built environment. Supporting this, daylight's associated human outcome benefits are underlined. Additionally, the paper explores strategies that optimize daylight in the built environment (glazing and fenestration strategies). A comprehensive literature review with a focus on daylight in the built environment and its associated value was conducted to identify knowledge gaps. The literature review focuses on daylight and its application in both office and assisted living environments (the two environments where daylight studies were conducted in this paper). Additionally, a light was shed on the associated value, or return on investment (ROI) of investing in daylight in the built environment. Two studies were carried out looking to understand the impact of various daylight levels on human health and wellbeing outcomes. The first study took place in an office environment. Subjects moved from a space with very minimal daylight to a space with more optimal daylighting conditions. The metrics included activity, sleep, and light levels (via the Philips Actiwatch). Additionally, surveys capturing environmental satisfaction, subjective wellbeing, organizational engagement, and performance at work were distributed. It was found that subjects responded well to the more optimally day lit space. Sleep improved by 10 min on average per night. Also, environmental satisfaction and subjective wellbeing survey scores showed measurable improvements. The second study focused on the impact of daylight in an assisted living environment. A group of residents living in various room types (receiving various daylight levels) took part in a two-week study. The metrics included activity, sleep, and light levels (via the Philips Actiwatch). Additionally, general health and personal routine surveys were administered. Certain patterns of behavior related to design attributes of rooms were found. For example, individuals residing in the "French Door room" type recorded the lowest average sleep levels. Both studies revealed which health outcomes could be important to stakeholders in justifying investing increased resources into a more research-driven design process. The paper

also identifies reasons for research and evidence based-design to be adopted more often, as well as its significance for stakeholders.

I. Background and Introduction to the Problem

A growing body of evidence demonstrates that the built environment plays a significant role in shaping the health and wellbeing outcomes of its users. There is a significant opportunity to invest in a deeper understanding of this relationship. With a deeper understanding, professionals will be able to make more informed design decisions that will promote improved health outcomes. The current research and evidence on this matter has not been sufficient to convince project stakeholders on a large scale to consistently adopt research and evidence-based design strategies. This has likely been due to a lack of detail on comprehensive human outcomes, as well as succinct evidence. With further understanding of how the built environment comprehensively impacts users, we can begin to make better decisions on how to implement these strategies. Additionally, improved human outcomes often provide other incentives for stakeholders, making it even more favorable to adopt these strategies. The further we move forward in understanding the specific impacts of various design strategies and parameters, the closer we can get to identifying metrics that matter and are meaningful to stakeholders (i.e. a return on investment of a particular design strategy). Thus, more of these strategies would likely be adopted more often.

In this paper, daylight will be explored as a parameter of the built environment that can be optimized for health and wellbeing outcomes. Daylight was chosen as an environmental variable since it is a design attribute that has been proven to have a major impact on human health and wellbeing (Boubekri, Cheung, Reid, Wang, & Zee, 2014). Among the many reasons daylight has a significant impact on our wellbeing, of great importance is its relationship with our bodies' circadian rhythms (Figueiro et al., 2017). A literature review was conducted to identify knowledge gaps in this area. Two real-world studies were then conducted to further understand the impact of daylight in the built environment on human outcomes. The first study to be discussed was conducted in an office environment in the Midwest region of the United States, while the second study was conducted in an assisted living environment in the Southwest region of the United States. Additionally, the studies explore various metrics and how they could potentially be of importance to project stakeholders for a return on investment (ROI). The map below shows the current relationships between building design, research, and potential ROI.

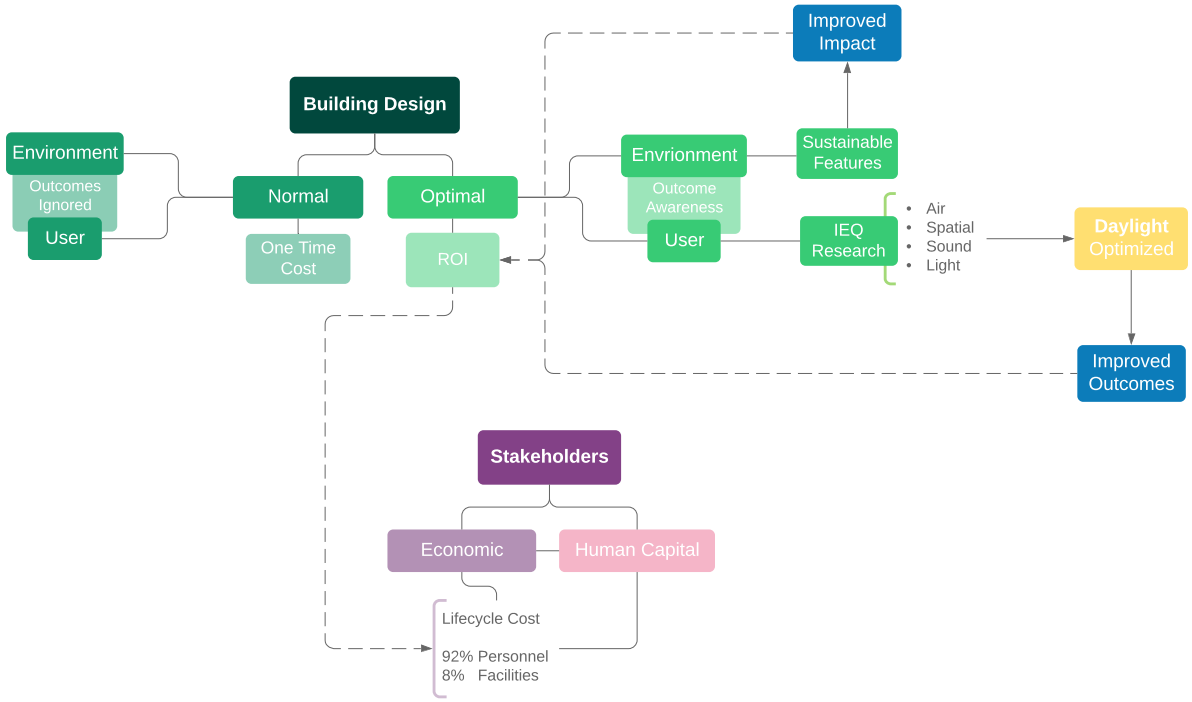


Figure 1. Thesis idea mapping

II. Research Questions

Daylighting in the built environment is an important metric since it has important impacts on health outcomes. More specifically, light has a strong relationship with our bodies' circadian rhythms. Through retinal light exposures, the brain's biological clock is stimulated. The daily pattern of light and dark falling on the retina sets the timing of our biological clocks. This compels us to stay awake during the day as well as sleep at night (Figueiro et al., 2017). It has been hypothesized that buildings where daylighting was a major design consideration, individuals' circadian systems would be exposed to lighting conditions that would reliably entrain the circadian system to local time on earth (Figueiro et al., 2017). Thus, this would improve sleep along with other measures of wellbeing and performance.

In the case of elderly individuals, the gradual yellowing of the lens along with the narrowing of the pupil that occur with age can disturb the body's circadian rhythm. This can contribute to a range of health problems. Essentially, as the eye ages, less sunlight makes its way through the lens to reach key cells in the retina that regulate the body's circadian rhythm (Turner, Van Someren, & Mainster, 2009). All of this means that circadian effective lighting such as daylight is that much more important in environments for the elderly population. In other words, the more circadian-effective light that does make its way through to the retina at necessary times, the better.

Can daylight could be justified as a strategic investment in various environments? Could it produce a case for a return on investment through its inherent human health outcome improvements in diverse cases? The goal of this research study is to understand the impact of daylight in diverse living and working environments, and how various individual outcome metrics (such as occupant health, wellbeing, and performance) could matter to project stakeholders.

III. Case Studies

3.1 Office Daylighting Study

The first study looked to further understand the impact of daylight on office employees. It took place in the Midwestern U.S. A group of 9 employees moved from relatively low indoor daylight levels (approximately 5 lux illuminance) to higher levels (approximately 300 lux illuminance). Parameters that were measured before and after the move included activity, sleep and light measures (via the Philips Actiwatch), environmental satisfaction surveys, subjective wellbeing surveys, organizational engagement surveys, and work performance surveys. The measurement periods took place for 1 week prior to the move, and 1 week after the move. During these periods, the Actiwatches were worn 24/7 by participants and the surveys were administered daily at 9am, 12pm, and 4pm, via a mobile survey application.

Figure 2. Original space before move (minimal or zero daylight levels)

Figure 3. New space after move (higher daylight levels)

3.2 Hacienda Assisted Living Daylighting Study

The second study focused on an assisted living facility in the Southwestern U.S. and how various daylight levels impacted resident's sleep and activity. A group of 7 individuals who lived in a

variety of room types and orientations were studied. The unique daylight levels in each individual's room, along with their daily light exposure was recorded and correlated with their sleep and activity levels. Personal routine and wellbeing surveys were administered before and after the study occurred. The study period took place over two weeks, during which participants wore the Actiwatch 24/7.

Figure 4. Site Plan of Assisted Living Facility in the Southwestern U.S.

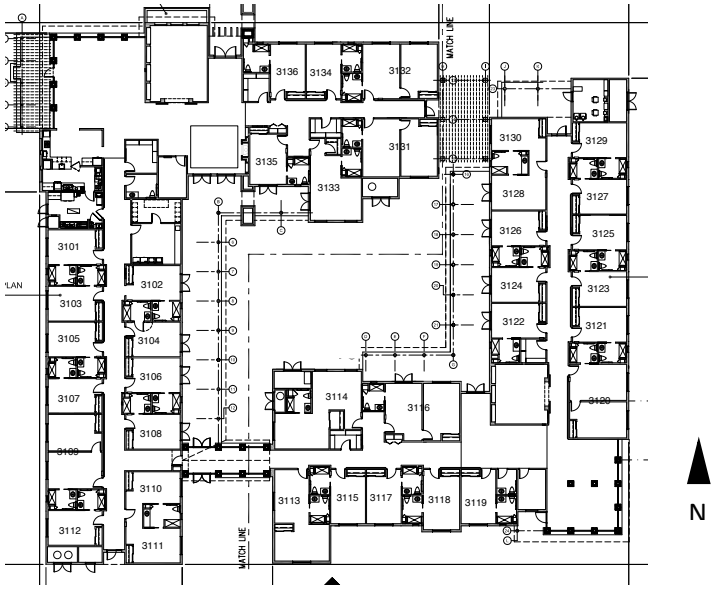


Figure 5. Building Plan of Assisted Living Facility in the Southwestern U.S.

IV. Methodology

4.1 Systematic Literature Review and Analysis

A systematic literature review and analysis was performed related to current research surrounding the impact of the built environment on wellbeing, performance, and the business case. A particular focus was shed on daylight, office environments, and elderly residential environments. Searches were conducted through Google Scholar with access to articles provided by the University of Arizona Libraries. A table was developed to categorize the articles. The table included columns on year, journal of publication, keywords, methods used, findings, and knowledge gap/scope for more. A complete has table has been included in the appendix section of this report.

4.2 Office Daylighting Study

In the office daylighting study, the measurement periods took place surrounding a move from individuals working in a minimally day lit environment to a more optimally day lit environment. The measurement periods took place for a duration of 1 week in the minimally day lit environment, and a duration of 1 week in the optimally day lit environment. In the minimally day lit environment, individuals received very little daylight at their desks (approximately 5 lux illuminance on average). In this environment, individuals sat at high partition semi-open cubicles. In the more optimally day lit environment, individuals received much more optimal levels of daylight at their desks (approximately 300 lux illuminance on average). This environment was much more open, with more square footage per person and low partition desks. Daylight measures were recorded with a lux meter on each individual's desk plane at 9am, 12pm, and 3pm in the summer.

During the measurement periods, the Philips Actiwatch was worn 24/7 by participants. Additionally, daily surveys were administered with questions on environmental satisfaction, subjective wellbeing, organizational engagement, and work performance. These surveys were

administered daily at 9am, 12pm, and 4pm during the measurement periods via a mobile survey application.

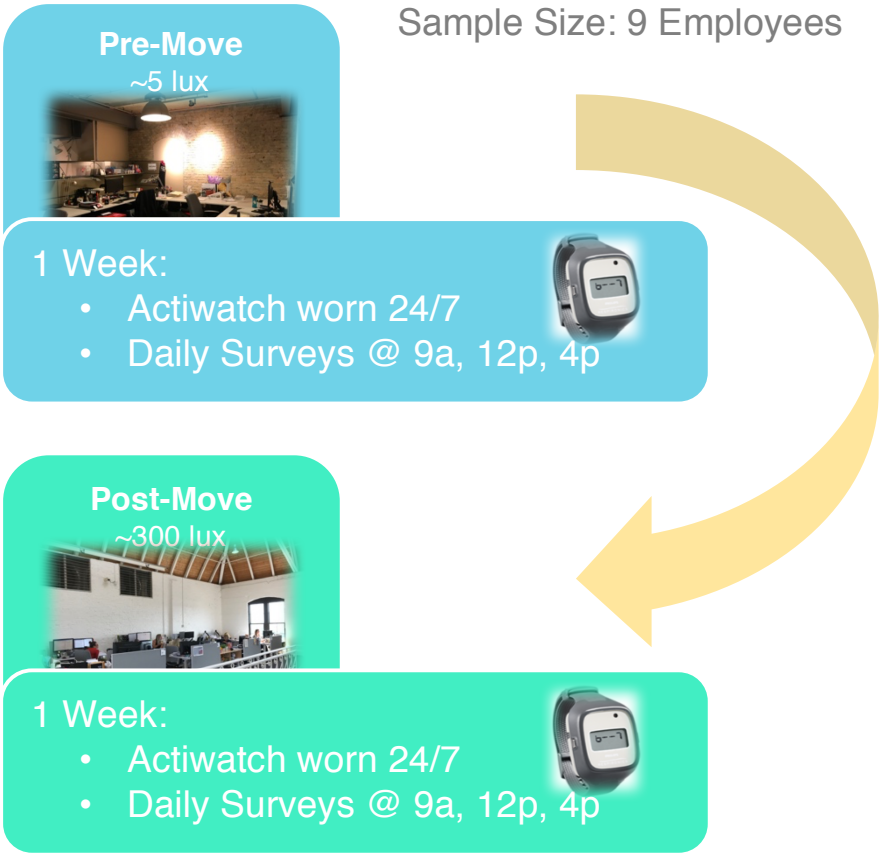


Figure 6. Office Daylight Study Methodology

Figure 7. Philips Actiwatch

4.3 Assisted Living Daylighting Study

In the assisted living daylighting study, individuals' sleep, activity, and light was recorded over a two week period. The Philips Actiwatch was worn 24/7 to capture these measures. Personal routine and wellbeing surveys were administered before and after the study occurred. The unique daylight levels were recorded in each individual's room with a lux meter. With the window shades fully open, the maximum daylight illuminance levels were recorded in 3 equal zones within the room from a working level height (28" from floor), and then averaged.

In this study, individuals lived in one of three room types. The first type was a "standard window room" with one casement window centered on the exterior wall. The second room type was a "French Door room." It consisted of one 'French Door' style door with two operable, fully glazed doors. Room sizes were standard in both of these types (~252 square feet). The third type of room consisted of a combination of both window types and was slightly larger overall (~400 square feet).

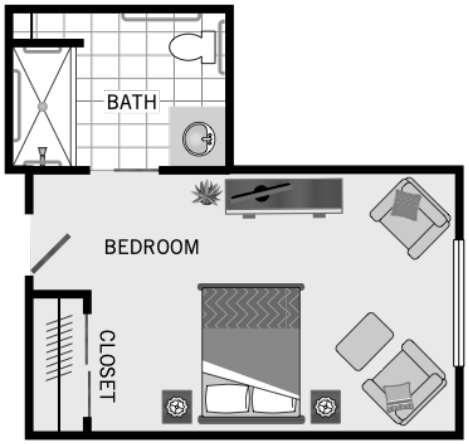


Figure 8. Typical room plan

Figure 9. "Standard Window room"

Figure 10. "French Door room"

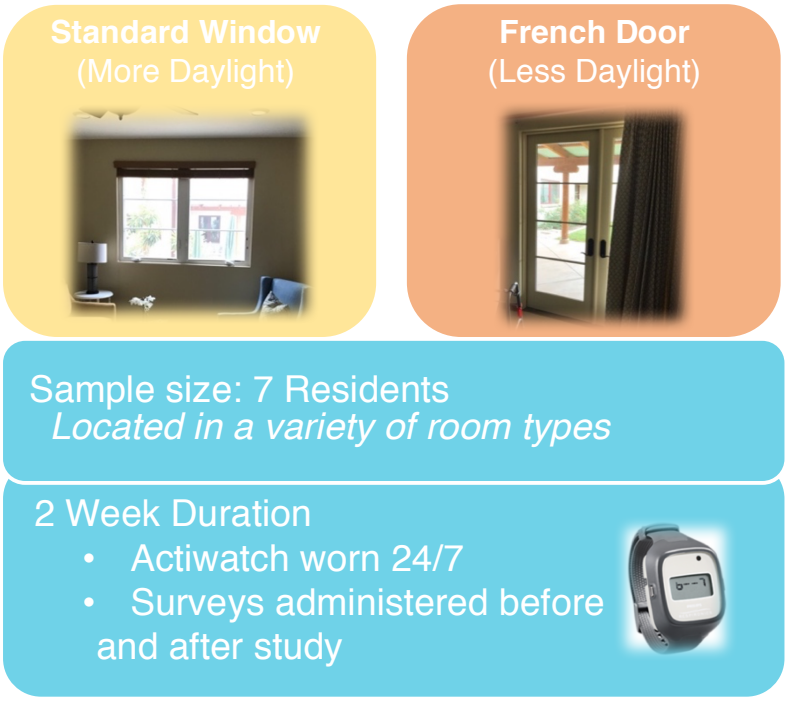


Figure 11. Assisted Living Daylight Study Methodology

In this study, the population studied was elderly. Some challenges of studying this population included the wide variety of activity patters of this age group and general health levels, which ultimately impact sleep metrics. Additionally, typical of this elderly population, sleep patterns were shown to vary generously. In studying this population, it is important to account for these variables.

V. Results

5.1 Systematic Literature Review and Analysis

It was found that current research on the built environment and its relationship to outcomes could use more detail in terms of inputs and outputs. Many papers describe general design parameters, but lack detail in terms of how much each variable (i.e. light, sound, air quality, etc.) was manipulated. Many of the papers referred to these optimized buildings as 'green', but lack specificity on what makes a particular building that way. Additionally, outcome measures lacked similar detail (i.e. how much of an impact on individuals' health). Overall, there is a need for more objective outcome measures. Taking it a step further, many papers list the potential for a business case or return on investment, but do not offer much detail in this regard. A majority of papers show the potential for the built environment to impact human health outcomes such as wellbeing and performance in a positive way. In particular, daylighting has been shown to have major benefits on these measures when optimized.

5.2 Office Daylighting Study

For the Office Daylighting Study, individuals responded positively to the new environment with better daylight levels. Environmental satisfaction scores showed dramatic improvement post-move. Although not scientifically significant due to a small number of participants, sleep was shown to improve by about 10 min/night on average, post-move. Average subjective wellbeing survey scores also improved by 4% overall (see figure 12). The specific questions that saw higher scores were "I'm thinking clearly", "I'm dealing with problems well", "I'm able to make up my mind about things", and "I'm feeling relaxed". Post-move organizational engagement scores went down by 10% on average. This, however, may be due to some staff changes during the study. The overall average for the work performance survey scores after the move went down by 1%. This was likely due to the combination of the less than ideal location of the new space (further from the rest of the office employees), and staff changes (which impacted engagement as well). However, some of the individual performance questions did see improvement. Questions that saw higher post-move scores were "I'm satisfied with my ability to manage stress today",

"I'm satisfied with my ability to meet deadlines today", and "I'm satisfied with the quality of the work I did today".

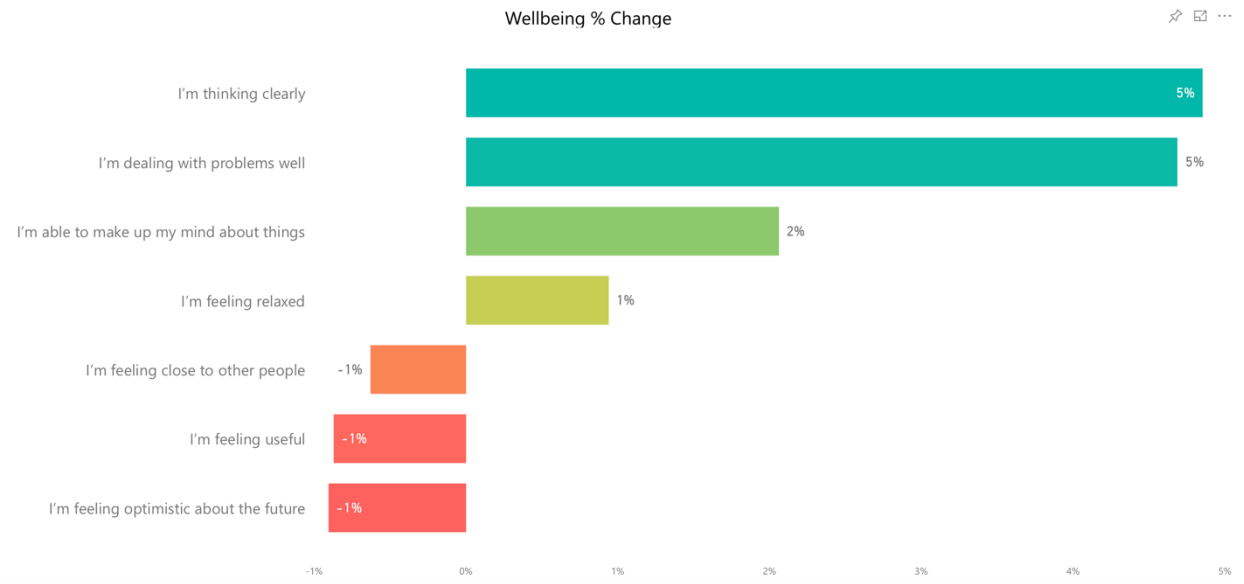


Figure 12. Wellbeing % Change (Before vs. After)

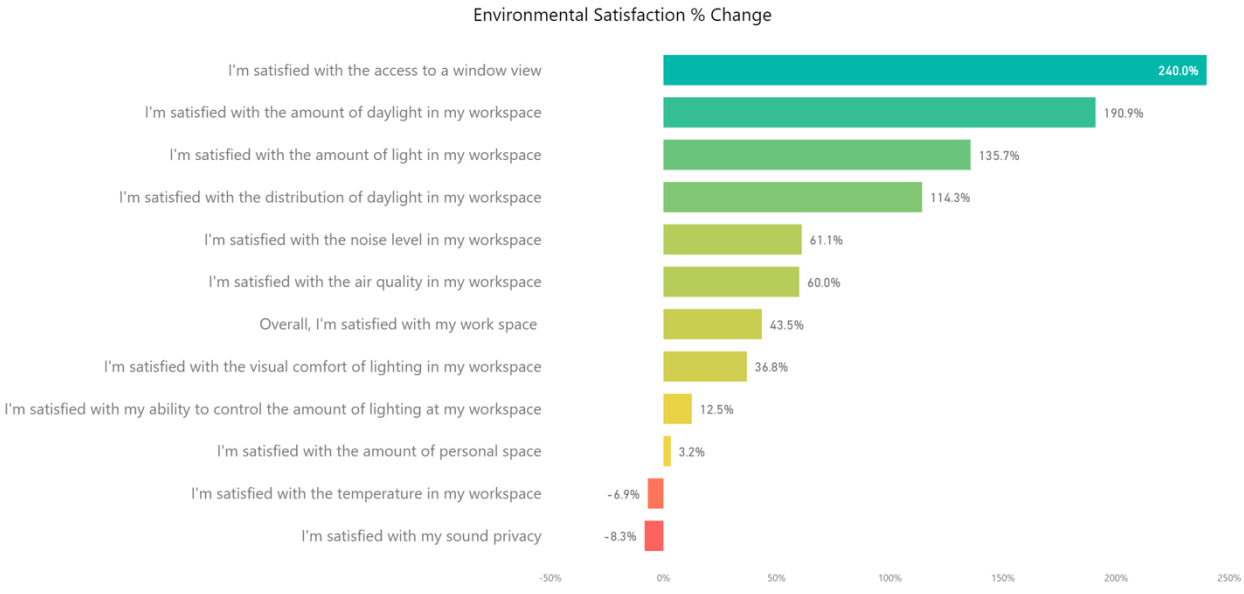


Figure 13. Environmental Satisfaction % Change (Before vs. After)

5.3 Assisted Living Daylighting Study

In the assisted living daylighting study, the study group displayed a wide variety of sleep patterns as well as activity levels. Although the results cannot be considered scientifically significant due

to a limited number of participants, it was observed that out of all individuals in the study, those who resided in the “French Door room” type (generally less daylight) had the lowest sleep quality (Figure 16). Other than that, there were not enough subjects or time to point to specific conclusions. One item to note is the amount of time that residents report they spend in their rooms. A majority of individuals (71.4%) report spending 6-9 hours in their room each day (Figure 14). This makes room daylighting conditions that much more important, since a great deal of time is spent in the individual rooms.

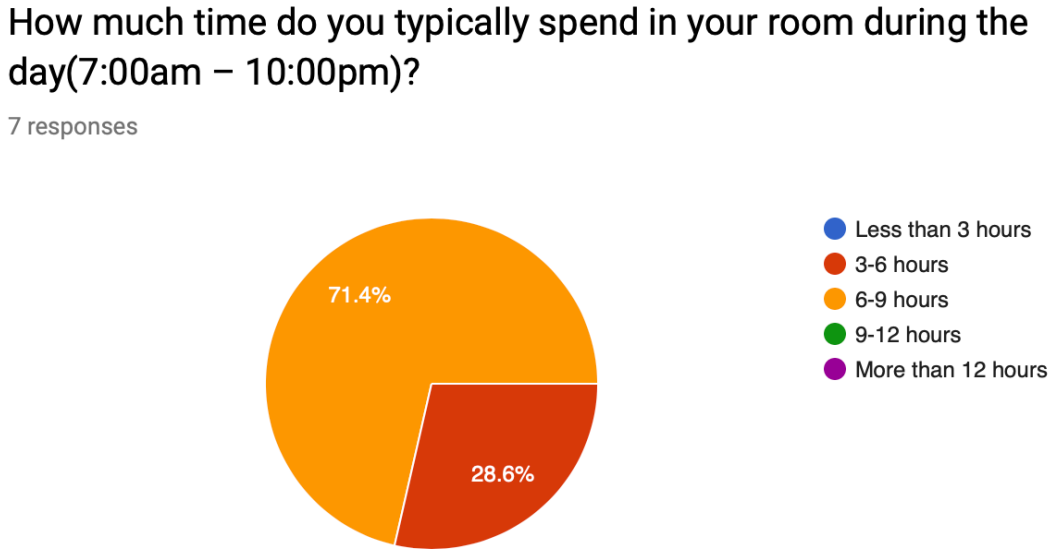


Figure 14. Time spent in room survey question

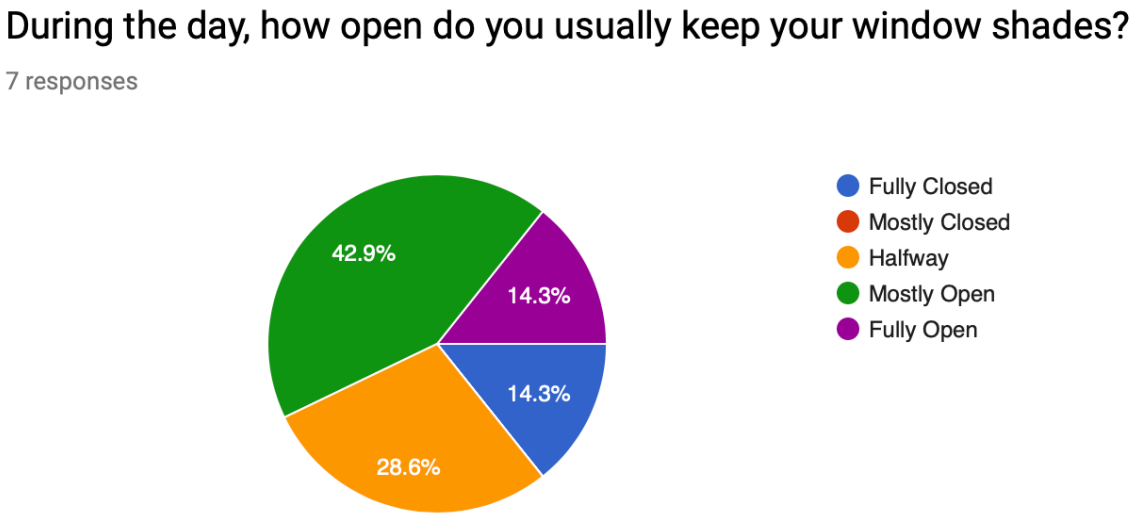


Figure 15. Window shade openness survey question

Figure 16. Map of results

VI. Conclusions

6.1 Overall Conclusions

The two research studies performed point to a relationship between interior daylight quality and human health outcomes that deserves further investigation. Despite the lack of scientifically significant evidence, there is enough anecdotal and observed evidence to warrant the awareness that daylight in the built environment is an important factor to consider in the design of spaces. The literature review demonstrates that daylight can have dramatic effects on health. In the office daylight study, it was found that the move to more optimally day lit spaces improved a variety of measures, especially environmental satisfaction scores. With the assisted living daylight study, it was observed that individuals in rooms with generally less daylight ("French Door room" type) had the lowest sleep quality of the group.

VII. Discussion

7.1 ROI Insights

After interviewing the owner of the studied assisted living facility to gain deeper insight on the real-world application of research and evidence, some general conclusions were made. This included the feeling that it is currently hard to find consistent, succinct evidence to back up particular design solutions with research that proves there are definite health benefits. It was stated that more studies of these types need to be performed. In regards to an associated return on investment of implementing research and evidence-based design elements, there is promising value according to the owner. On one hand, if it can eventually be proven that particular design solutions are linked to greater health (i.e. better sleep quality, longer life span, etc.) there could be a return on investment for this as seen as a competitive advantage amongst similar facilities. This could be a way to differentiate one building from the next, with linkages between better design and documented improved outcomes. On the other hand, designing with the latest research and evidence is a selling point in itself through its marketing value to the individuals who are in this market. The owner believes these individuals may even feel better or more comfortable within these types of facilities without even realizing it, since many of these design parameters impact the subconscious mind.

7.2 Design Recommendations (Assisted Living Daylight Study)

For the assisted living daylight study, several design recommendations have been made in order to optimize daylight levels in resident's rooms. At a site and building orientation level, it is recommended to rotate the entire facility 90 degrees in order to allow more resident rooms to receive either north or south light, instead of the harsh east and west daylight conditions. This would allow for a more even quality of daylight throughout the day, with less glare and heat gain. Additionally, shading devices can be designed more easily for these conditions. At the individual room and fenestration level, it is recommended to add clerestories above the existing widows along with light shelves. This would allow daylight to be bounced deeper into the space, allowing for higher daylight levels throughout the room. In the most optimal case it would be

recommended to move the windows to align with a cross-directional wall to bounce daylight even further into the space. Daylight simulation studies were conducted in Velux Daylight Visualizer to visualize the differences in daylight penetration. As can be seen in the daylight studies (see appendix), daylight generally penetrated deeper into the space within the clerestory and light shelf conditions in both the "standard window" and "french door" rooms. The most optimal conditions (deepest daylight penetration) were shown with the wall-aligned clerestory and light shelf conditions.

Ideally, the light shelves should be sized to shade the bottom window portion of the assembly from the Spring Equinox through the Fall Equinox. This would allow light in for passive heating in the winter months, while keeping the rooms cooler in shade for the warmer part of the year, appropriate for this climate zone. This would likely lead to a more comprehensive return on investment, since not only would the deeper daylight penetration likely improve occupant health and wellbeing, but the shading would allow for less building energy usage (for heating and cooling).

(See Appendix for related visuals)

7.3 General Discussion

These studies add to the body of evidence demonstrating the significance of the built environment and its impact on outcomes. The research studies performed highlight a relationship that warrants further investigation. With further understanding of how the built environment impacts users, we can make improved, more informed design decisions and ultimately improve outcomes. When these improved outcomes are documented, a case can be made for investing increased resources into research and evidence-based design of new projects. Stakeholder education is of utmost importance in this regard. With continued research and documentation of design parameters and outcomes, we can get closer to justifying the need for research and evidence-based design in the design process more often.

It is worth noting that there are many benefits of collecting both objective physiological data (i.e. Philips Actiwatch), along with subjective data (i.e. survey questionnaires). In these studies, the

objective data was combined with subjective data to make conclusions. This methodology is powerful compared with conducting a more simple post-occupancy evaluation (POE) thanks to the rich balance of insights (subjective and objective). It takes both the objective and subjective to balance out and gain a deeper understanding of the situation.

7.4 Limitations

There are several limitations to both studies. In both studies, scientifically significant results were not achieved due to the small sample size and relatively short duration of each study respectively. In the office daylight study, subjects did not always adhere exactly to the daily survey schedule. Perhaps daily reminders such as SMS texts along with rewards or prizes for completion could assist in improving adherence to the daily schedule. In both studies, the Actiwatches were often taken off for showers, and individuals occasionally did not wear them for brief periods of time. With the assisted living daylight study, limitations included the wide variety of health levels and conditions amongst subjects as well as their wide variety of sleep patterns in general (typical of this elderly population). Age and medical backgrounds should also be studied more carefully when selecting subjects since these factors were found to have a significant impact on sleep and activity.

7.5 Future Research Potential

There is tremendous potential for future research in both the office daylight study, and assisted living daylight study. Both these studies could be repeated, recruiting more subjects and utilizing a longer duration, to make the study scientifically significant. Other factors such as daily routines and habits, especially for an elderly population, should be recorded carefully and analyzed with the data for any significant associations. With the assisted living facility, systematic interviews of employees would give a great deal of insight into the inner workings of the facility, as well as patterns of residents. Perhaps a series of on-site participant observations at different times of the day could provide more information. With an office environment, considering the more detailed relationships within the space would be valuable. For example, when the office employees moved to the new space, did they miss their previous neighbors or colleagues? Perhaps the new

space provided more opportunities for social interaction? Another question is whether individuals' increased activity levels due to the locations of restrooms, pantries, or copiers? In this respect, spatial layouts before and after also need to be examined carefully. It would also be worth considering occupant locations throughout the day perhaps utilizing GPS or RFID sensors. Could wearable devices that measure heart rate and stress be implemented? Finally, it could also be valuable to study electrical circadian lighting solutions compared with natural lighting solutions to see if there are any differences in health outcomes.

APPENDIX A: LITERATURE REVIEW

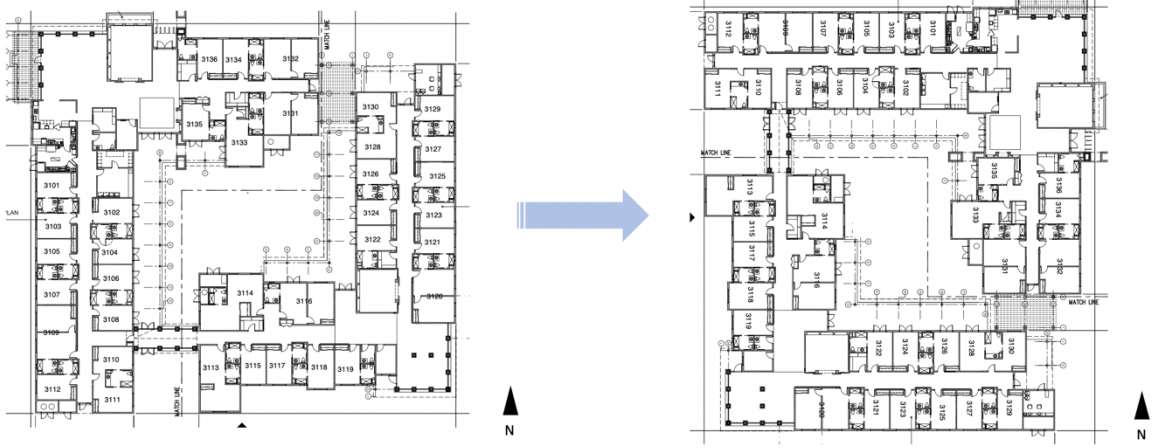
	Systematic Lit Review					
	Ryan Shindler MS. Arch HBE Thesis					
Year	**Article (Author)**	**Journal/Source**	**Keywords**	**Methods**	**Findings**	**Knowledge Gap/Scope for More**
2010	Effects of Green Buildings on Employee Health and Productivity (Amanjeet Singh, Matt Syal, Sue C. Grady, Sinem Korkmaz)	American Journal of Public Health	air quality; health; IEQ; productivity; office; public health; green buildings	An investigation of the effects of improved indoor environmental quality (IEQ) on percieved health and productivity in occupants who moved from conventional to 'green' (LEED rated) office buildings	-Improved IEQ contributed to reductions in perceived absenteeism and work hours affected by asthma, respiratory allergies, depression, and stress as well as self-reported improvements in productivity	-Exact design elements not specified; i.e. what were the exact environmental features? -How much were they responsible for improvements? -How do the outcomes impact the business case?
2011	An Overview of the Influence of Physical Office Environments towards Employees (N. Kamaruzaman, A. A. Saleh, S. Z. Hashim, H. Hashim, A. A. Abdul-Ghani)	Procedia Engineering	employees; Indoor environment; performance; IEQ; productivity; office; Satisfaction; review;	Lit review where the relationship workplace design, indoor temperature, color, noise, and interior plants have on wellbeing and performance are discussed	-Indoor environments in an office have a great influence on employees' attitudes, behaviors, satisfaction and work performance. -Research demonstrates that productivity bears a close relationship to indoor environment quality.	-What were the exact levels of improvement? -How do the outcomes impact the business case?
2015	Daylight in office buildings- Impact of design on personal light exposures, sleep, and mood (Mariana G. Figueiro, Bryan Steverson, Judith H. Heerwagen, Mark S. Rea)	Presentation at 28th CIE (International Commission on Illumination)	office; circadian rhythms; daylight; light;	The impact daylight had on circadian functions regulating sleep, mood, and alertness was looked into in the winter compared with late spring.	-The amount of daylight occupants recieve is largely dependent on their behavior as well as furniture placement. -Participants recieved more circadian stimulating light (CS) in the late spring than in the winter	-Exact design elements not specified; i.e. what were the exact environmental features? -How much were they responsible for improvements? -How do the outcomes impact the business case?
2014	Daytime light exposure- Effects on biomarkers, measures of alertness, and performance (Levent Sahin, Brittany M. Wood, Barbara Plitnick, Mariana G. Figueiro)	Behavioural Brain Research	office; red; red light; performance; Light;	13 subjects experienced dim light, red light, and white light and effects from these conditions were recorded.	-Red light was found to increase short-term performance (significantly reduced response time and higher throughput in performance) -These results suggest that red light can be used to increase daytime performance	-More specific performance outcomes; -Need linkage to the business case
2014	Effects of realistic office daylighting and electric lighting conditions on visual comfort, alertness and mood (A Borisuit, F Linhart, J-L Scartezzini, M Munich)	Lighting Research & Technology	visual comfort; Light; performance; workplace; alertness; mood;	A test of whether differenct photometric variables influence visual perception and the comfort of the lighting along with mood, alertness and wellbeing	-Subjects were found to prefer daylighting (DL) over electric lighting (EL) for visual acceptance and glare -Subjects felt sleepy earlier in the afternoon under EL -Physical wellbeing became worse in the afternoon only under EL	-More specific outcomes; -No performance outcomes; -Need linkage to business case
2010	Effects of the physical work environment on physiological measures of stress (Julian F. Thayer, Bart Verkuil, Jos F. Brosschot, Kevin Kampschroer, Anthony West, Carolyn Sterling, Israel C. Christie, Darrell R. Abernethya, John J. Sollers, Giovanni Cizza, Andrea H. Marques and Esther M. Sternberg)	European Journal of Preventive Cardiology	workplace; stress responce; heart; health; outcomes; office; cortisol; heart rate variability; lighting; Air Quality;	Study investigating the effects of the physical work environment on two physiological measures of the stress response (heart rate variability and salivary cortisol). Workers in two differenct office settings were studied.	-It was found that the old office space with poorer lighting and air quality than the new space was associated with less vagally mediated HRV at night and a higher morning cortisol rise (opposite of the typical healthy pattern).	-More specific design attributes; No performance outcomes; -Need linkage to business case
2014	Enlightened thoughts- Associations with daylight versus electric light, preference formation, and recovery from stress (F. Beute, Y.A.W. de Kort)	Proceedings of EXPERIENCING LIGHT 2014: International Conference on the Effects of Light on Wellbeing	wellbeing; preference; health; daylight;	Investigation of associations with, and preference for daylight versus electric light; specific assesments in terms of preference, mood, and performance were utilized.	-Daylight was found to generate more positive associations and higher preference ratings than electric light.	-More specific design attribute specification; -More specific outcome measures; -Need linkage to business case
2016	Environmental perceptions and health before and after relocation to a green building (Piers MacNaughton, John Spengler, Jose Vallarino, Suresh Santanam, Usha Satish, Joseph Allen)	Building and Environment	IEQ; thermal comfort; noise; ergonomics; air quality; green buildings; lighting	Research investigating the objective impact of green buildings on health. Indoor environmental quality (IEQ), self-reported health, and heart rate in 30 participants from green and conventional buildings were tracked for two weeks.	-Participants reported improved air quality, odors, thermal comfort, ergonomics, noise and lighting and fewer health symptoms in green buildings. -A 1000 ppm increase in indoor CO2 concentration was found to cause 43% more symptoms, and a 2 bpm higher heart rate	-More specific design attribute specification; -Need linkage to business case
2014	Impact of Windows and Daylight Exposure on Overall Health and Sleep Quality of Office Workers (Mohamed Boubekri, Ivy N. Cheung, Kathryn J. Reid, Chia-Hui Wang, Phyllis C. Zee)	Journal of Clinical Sleep Medicine	sleep; daylight; productivity; office; light;	Study examining the impact of increased daylight exposure on the health of office workers. Subjective wellbeing, activity and sleep quality were measured.	-Workers in windowless environments reported poorer sleep quality than their counterparts in environments with windows. -Workers with windows reported more physical activity. -Workers without windows also reported higher role limitation due to physical problems and vitality.	-More specific performance outcomes; -More specific design parameters (i.e.how much daylight is optimal?); -Need linkage to the business case
2012	Indoor Environment and Productivity in a Green Building (Miwa Higuchi, Shin-ichi Tanabe, Naoe Nishihara, Kotaro Ito, Asami Nagareda, Tsuyoshi Ito, Katsuaki Wada, Setsuko Yoshino, Ryohei Mase)	10th International Conference on Healthy Buildings 2012	office; IEQ; satisfaction; green buildings; air quality;	An evaluation of office workers' productivity in relationship to their indoor environment and activities before and after relocation to a green building.	-Satisfaction with the studied green office building was found to be higher than the original conventional office building. -Specifically, satisfaction with the thermal environment and air quality was found to be higher.	-Need linkage to business case
2015	Lack of exposure to natural light in the workspace is associated with physiological, sleep and depressive symptoms (Francine Harb, Maria Paz Hidalgo, Betina Martau)	Chronobiology International	light; depressive symptoms; windows; sleep quality; wellbeing; employees; office; daylight;	Study aiming to evaluate the effects of exposure or lack of exposure to natural light on cortisol and melatonin levels. 10 employees with windows were compared with 10 employees without windows.	-Lack of exposure to natural light is related to high levels of cortisol and lower levels of melatonin at night. -This in turn relates to depressive symptoms and poor quality of sleep.	-More specific performance outcomes; -More specific design parameters (i.e.how much daylight is optimal?); -Need linkage to the business case
2016	Occupant productivity and office indoor environment quality (Yousef Al Horr, Mohammed Arif, Amit Kaushik, Ahmed Mazroei, Martha Katafygiotou, Esam Elsarrag)	Building and Environment	review; IEQ; productivity; outcomes; daylight; thermal comfort;	A review of existing literature on the relationship between indoor environmental quality and occupant productivity in an office environment. Outlines eight Indoor Environmental Quality (IEQ) factors that influence productivity.	-Important to remember that various IEQ factors have significant interactions and crossover between them -For example, daylight has a direct interaction with the thermal state of an office	-More specific design parameters; -More specific outcome measures; -Need linkage to business case
2014	Office lighting and personal light exposures in two seasons- Impact on sleep and mood (MG Figueiro, MS Rea)	Lighting Research & Technology	light; sleep quality; seasons; employees; office; daylight	A study was conducted measuring the circadian light-dark and activity-rest patterns of individuals working in a building designed to provide daylight availability. These measures were taken in winter and summer. Sleep and mood data was also recorded.	-A significant increase in light exposure was found in the summer. -Sleep quantity and quality were found to be significantly higher in summer than in winter.	-More specific design parameters; -Lack of performance outcome measures; -Need linkage to business case
2013	Satisfaction of occupants toward indoor environment quality of certified green office buildings in Taiwan (Han-Hsi Lian, Chen-Peng Chen, Ruey-Lung Hwang, Wen-Mei Shih, Shih-Chi Lo, Huey-Yan Liao)	Building and Environment	office; IEQ; thermal comfort; Satisfaction; air quality; green buildings;	Study investigating and comparing green and conventional office buildings in Taiwan; various aspects of IEQ were compared along with the respective correlated satisfaction	-Overall IEQ satisfaction as well as the proportion of occupants voting for satisfaction in the green buildings were both greater than their counterparts in conventional buildings	-More specific human outcome measures; -Lack of performance outcome measures; -Need linkage to business case
2017	The impact of daytime light exposures on sleep and mood in office workers (Mariana G. Figueiro, PhD, Bryan Steverson, MA, Judith Heerwagen, PhD, Kevin Kampschroer, MA, Claudia M. Hunter, PhD, Kassandra Gonzales, MS, Barbara Plitnick, RN, Mark S. Rea, PhD)	Sleep Health	outcomes; workplace; phasor analysis; sleep; circadian rhythms; light exposure; mood;	The correlation between circadian-effective light and sleep and mood is explored. Personal devices measuring circadian light exposure were worn by office workers. This data was then related to measures of sleep and mood.	-Receiving high levels of circadian-effective light in the morning is associated with reduced sleep onset latency (especially in winter), increased sleep quality and increased circadian entrainment. -High levels of circadian-effective light during the entire day are associated with reduced depression, increased sleep quality and increased circadian entrainment.	-Lack of performance outcome measures; -Need linkage to business case
2016	The impact of the ambient environment on occupant productivity (Mark Mulville, Nicola Callaghan, David Isaac)	Journal of Corporate Real Estate	behavior; health; productivity; wellbeing; asset management; comfort;	Paper looks to define the impact the ambient environment has on perceived comfort, health, and wellbeing. A study is conducted utilizing an occupant survey along with monitoring of ambient environmental conditions.	-The ambient environment can have a significant impact on occupant comfort, health and wellbeing -Findings of the occupant survey found a significant different in perceived IAQ by floor -Workplace behavior was found to have a significant impact on wellbeing -Individuals who take breaks more often are less likely to experience headaches	-More specific design parameters; -Need linkage to business case;
2017	The impact of working in a green certified building on cognitive function and health (Piers MacNaughton, Usha Satish, Jose Guillermo Cedeno Laurent, Skye Flanigan, Jose Vallarino, Brent Coull, John D. Spengler, Joseph G. Allen)	Building and Environment	office; cognitive performance; sick building syndrome; performance; green buildings;	A study where workers in green certified buildings were compared with their counterparts in non-green buildings. Outcome measures including cognitive function along with indoor environmental quality were measured.	-Workers in green certified buildings scored 26.4% higher on cognitive function tests. -These workers also had 30% fewer sick building symptoms.	-More specific design parameters

	Systematic Lit Review					
	Ryan Shindler MS. Arch HBE Thesis					
Year	**Article (Author)**	**Journal/Source**	**Keywords**	**Methods**	**Findings**	**Knowledge Gap/Scope for More**
2014	Environmental influences on healthy and active ageing: a systematic review (Michael Annear, Sally Keeling, Wilkinson, Tim, Grant Cushman, Bob Gidlow)	Ageing and Society	aged; ageing; multiculturalism; social participation; empowerment; environmental degradation; urbanism	Paper exploring evidence for environmental influences on older adult health and activity participation. Identifies current knowledge gaps and limitations. Offers reccomendations for future research.	-A large number of studies were found to identify that environmental conditions play an important role in influencing the health outcomes and activity participation of older adults. -More qualitative and mixed-methods research is required to explore the dynamic pathways where environmental conditions might influence the health and activity participation of older adults.	-More qualitative and mixed-methods research
2012	The impact of the built environment on health across the life course: design of a cross-sectional data linkage study (Karen Villanueva, Gavin Pereira, Matthew Knuiman, Fiona Bull, Lisa Wood, Hayley Christian, Sarah Foster, Bryan J Boruff, Bridget Beesley, Sharyn Hickey, Sarah Joyce, Andrea Nathan, Dick Saarloos, Billie Giles-Corti)	BMJ Open	aged; ageing; life cycle; multiculturalism; social participation; urbanism	Study looking into the impact the built environment has on the health of a variety of age groups. Looks into correlations with objective clinical and mental health outcomes.	-Study aiming to build stronger case for changing neighborhood design conducive to healthy living. -Study will use exsisting data to examine associations within and across different life stages.	-Wider variety of data imputs
2014	Built Environment and Elderly Population Health: A Comprehensive Literature Review (Noe Garin, Beatriz Olaya, Marta Miret, Jose Luis Ayuso-Mateos, Michael Power, Paola Bucciarelli, Josep Maria Haro)	Clinical Practice & Epidemiology in Mental Health	built environment; elderly people; literature review; mental health; physical health; quality of life; wellbeing	A literature review looking into research related to the impact of the built environment on the health of elderly people.	-Evidence reviewed in this paper suggests that some built environment variables likely impact health. Further investigation is needed to clarify the relationship.	-Larger samples using longitudinal studies
2014	The interactive effects of housing and neighbourhood quality on psychological well-being (McKenzie L Jones-Rounds, Gary W Evans, Matthias Braubach)	Journal of Epidemiology & Community Health	built environment; psychological wellbeing; mental health; physical health; quality of life; wellbeing	Study looking into the negative health effects of substandard housing and inadequate neighborhoods and if an improved physical neighborhood quality could partially offset some negative effects of poor housing quality.	-Both substandard housing quality and poor neighborhood quality contribute to lower psychological wellbeing. -Better neighborhood quality was found to buffer against the negative effects of poor housing quality on psychological wellbeing.	-Lack of details on what constitues better environmental quality
2012	Streets ahead? The role of the built environment in healthy ageing (Elizabeth Burton)	Perspectives in Public Health	older people; research; aging; social interaction; objectives; studies	Overview of how the built environment can contribute to healthy ageing. Outlines key issues that need to be addressed for the creation and adaptation of environments to be successful.	-Items such as more energy efficient, insulated homes, along with better ventilation and other residential-scale design interventions are presented.	-Lack of detail on what and how much needs to be done to improve environments for healthy ageing
2011	Good places for ageing in place: development of objective built environment measures for investigating links with older people's wellbeing (Elizabeth J Burton, Lynne Mitchell and Chris B Stride)	BMC Public Health	built environment; psychological wellbeing; mental health; physical health; quality of life; wellbeing; older people	A paper exploring how individual characteristics of older people's residential environments contribute to their wellbeing, in order to provide the basis for evidence-based housing/urban design along with the development of interventions.	-Study suggests that there may be characteristics of residential environments of potential relevance for older people's lives that have been largely overlooked in most research to date.	-Doesn't specify particular paramaters to be modified in the environment and how much if any
2018	Systematic review of the physical home environment and the relationship to psychological well-being among community-dwelling older adults (Shannon M. Trecartina and Sherry M. Cummings)	Journal of Gerontological Social Work	aging-in-place; built environment; functional impairment; psychological well-being; ecological model of aging	Systematic lit review that looks into the relationships between the physical home environment, functional impairment, and psychological wellbeing among older adults who live in community settings.	-Knowledge of the relationships between these variables is still in early stages. -Associational relationships are established, but the nature of the relationships is clouded by the inconsistency of measurement across studies. -Objective and subjective features of the physical home environment are linked to psychological wellbeing throughout the literature.	-Consistency of measurement across studies is needed; -More detailed measurements needed
2016	Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature (Yousef Al horr, Mohammed Arif, Martha Katafygiotou, Ahmed Mazroei, Amit Kaushik, Esam Elsarrag)	International Journal of Sustainable Built Environment	occupant wellbeing, indoor environment quality, occupant comfort, offices, green buildings	Extensive literature review that establishes links between IEQs and occupant wellbeing and comfort.	-Design of buildings should consider occupant wellbeing parameters at the beginning of the design process.	-Lack of higher level business bottom line impacts; -Limited to mostly office buildings
2012	Field measurements of circadian light exposures, activity levels and degrees of circadian entrainment in healthy older adults and in persons with Alzheimer's disease (Mariana Figueiro, Patricia Higgins, Thomas Hornick, Ashritha Epur, MarkRea)	Alzheimer's & Dementia	sleep; daylight; Alzheimer's disease; light; circadian rhythm	Study measuring and comparing circadian light, activity and circadian entrainment in healthy older adults and in those with Alzheimer's disease.	-Circadian disruption (resulting from reduced circadian light exposures during daytime hours) could be an underlying contribution to sleep problems commonly experienced by those with Alzheimer's.	-Lack of potential solutions described; -No specific design details included

APPENDIX B: DESIGN RECCOMENDATIONS

Site-Level Recommendations:

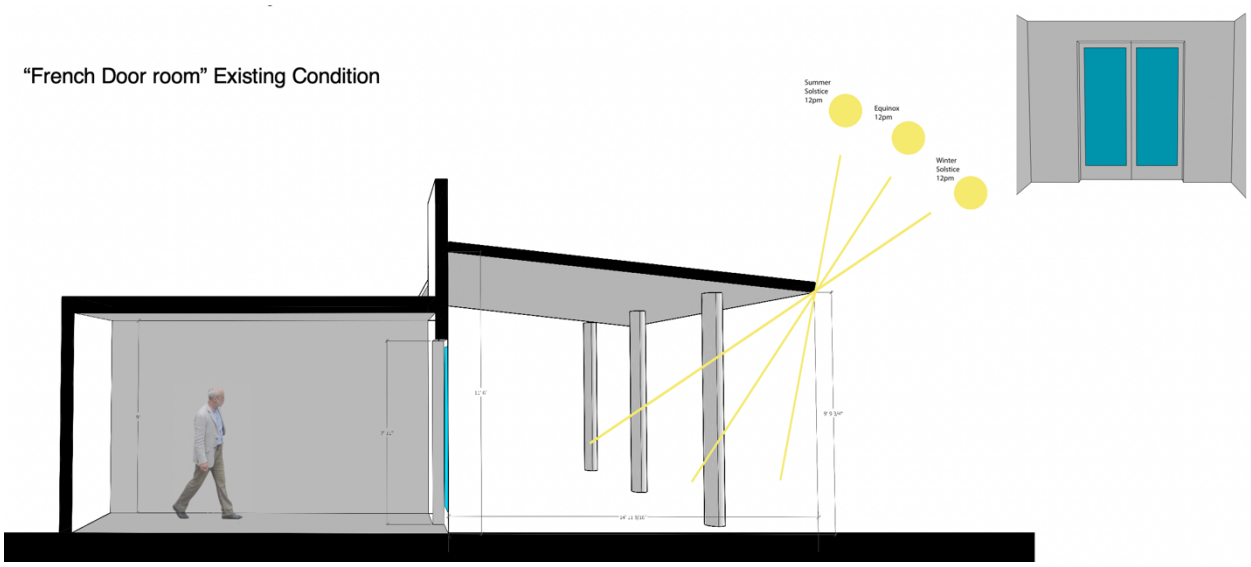
Recommended: Rotate plan 90 degrees clockwise
(For potential new, future project)

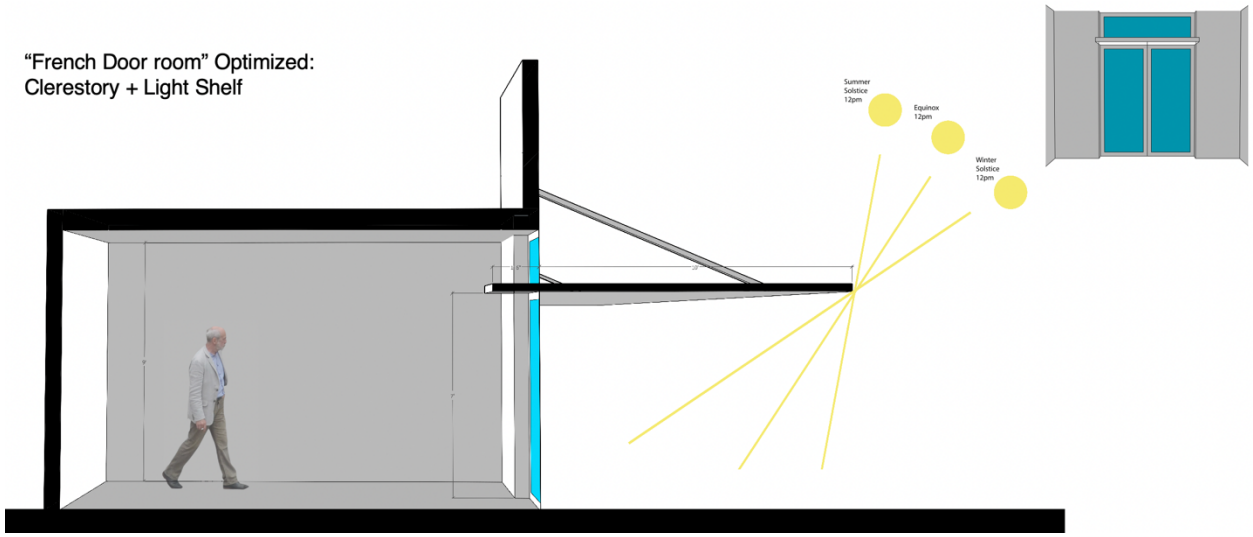


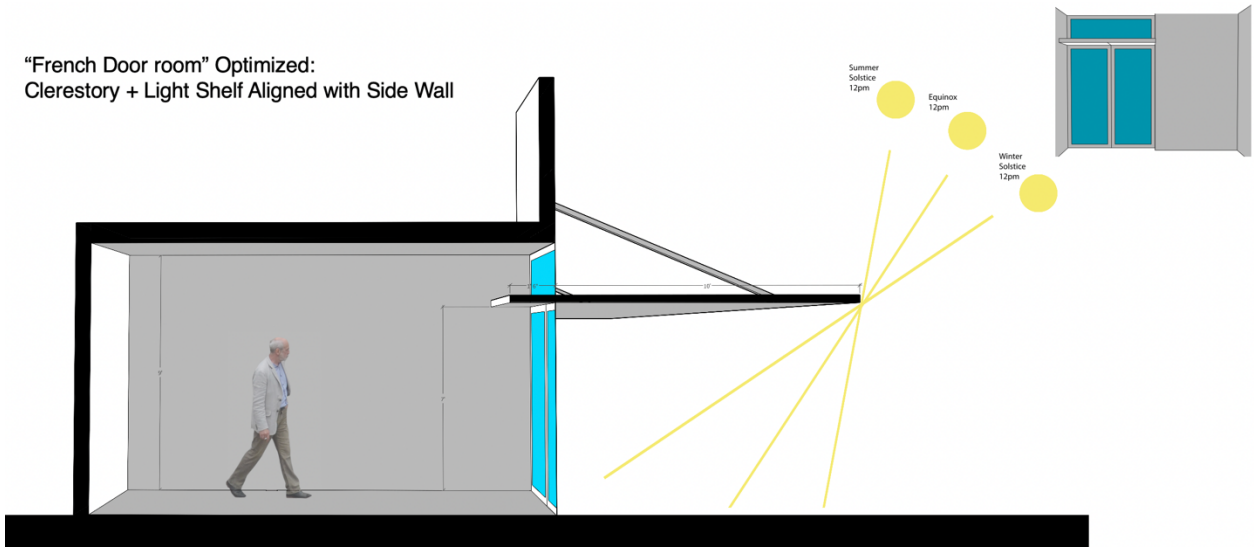
Result: More rooms are oriented N-S for better daylight conditions

- More even quality of daylight throughout the day
- Less glare and heat gain
- Easier to design architectural shading devices

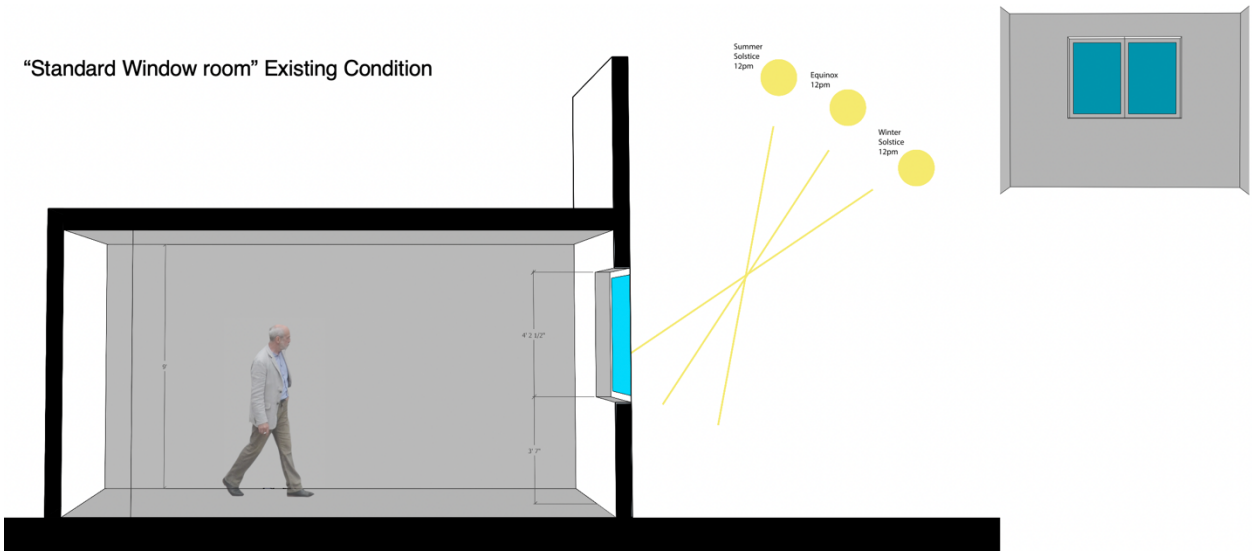
Room/Fenestration-Level Recommendations for “French Door room” (South Facing):

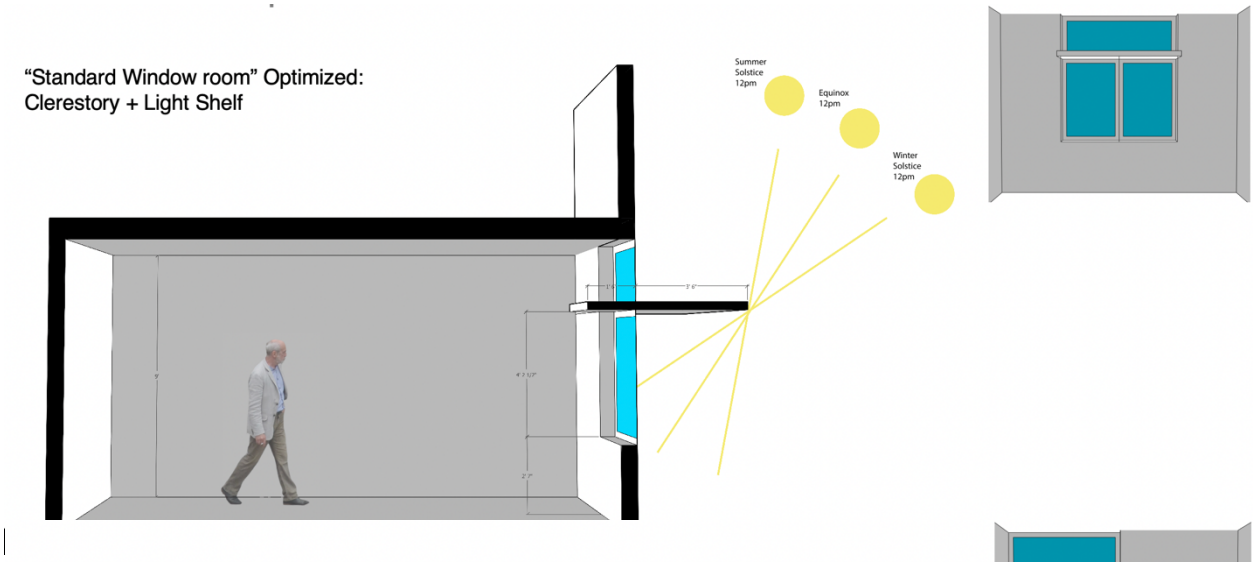


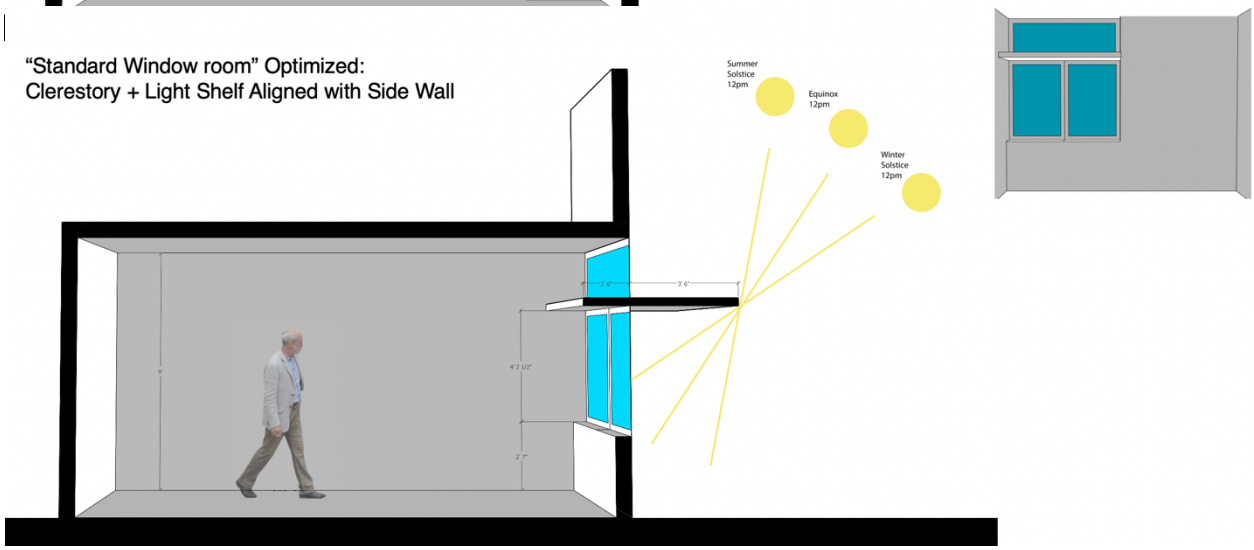




Room/Fenestration-Level Recommendations for “Standard Window room” (South Facing):

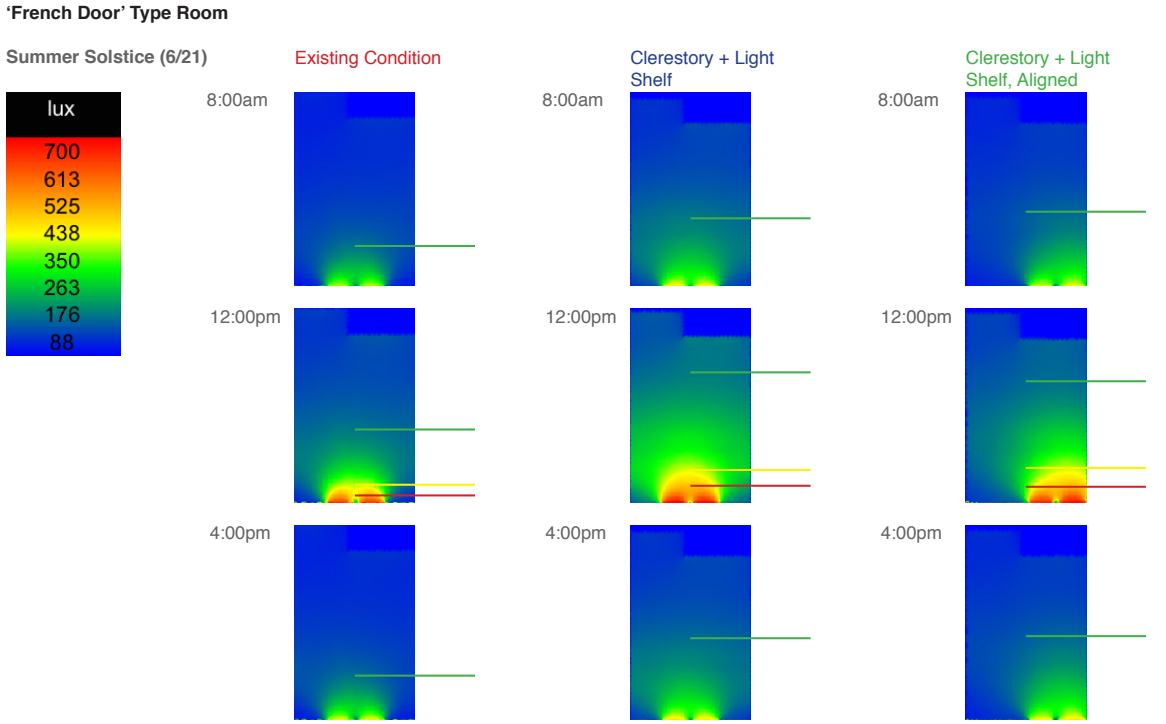


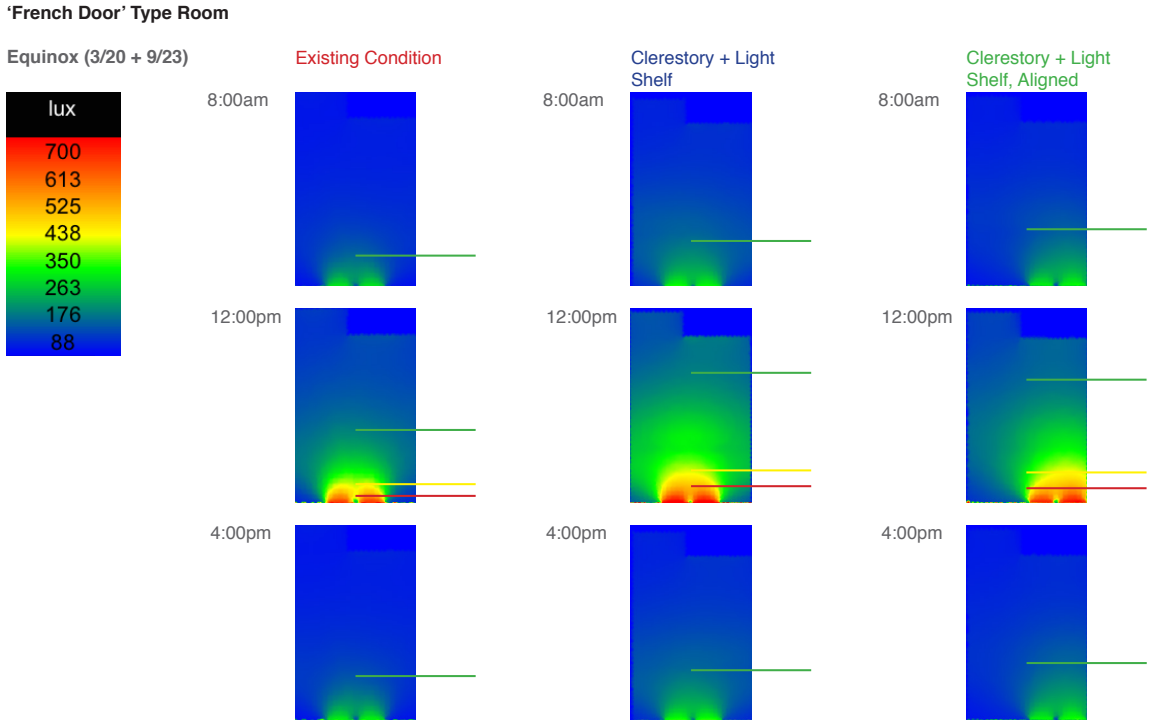




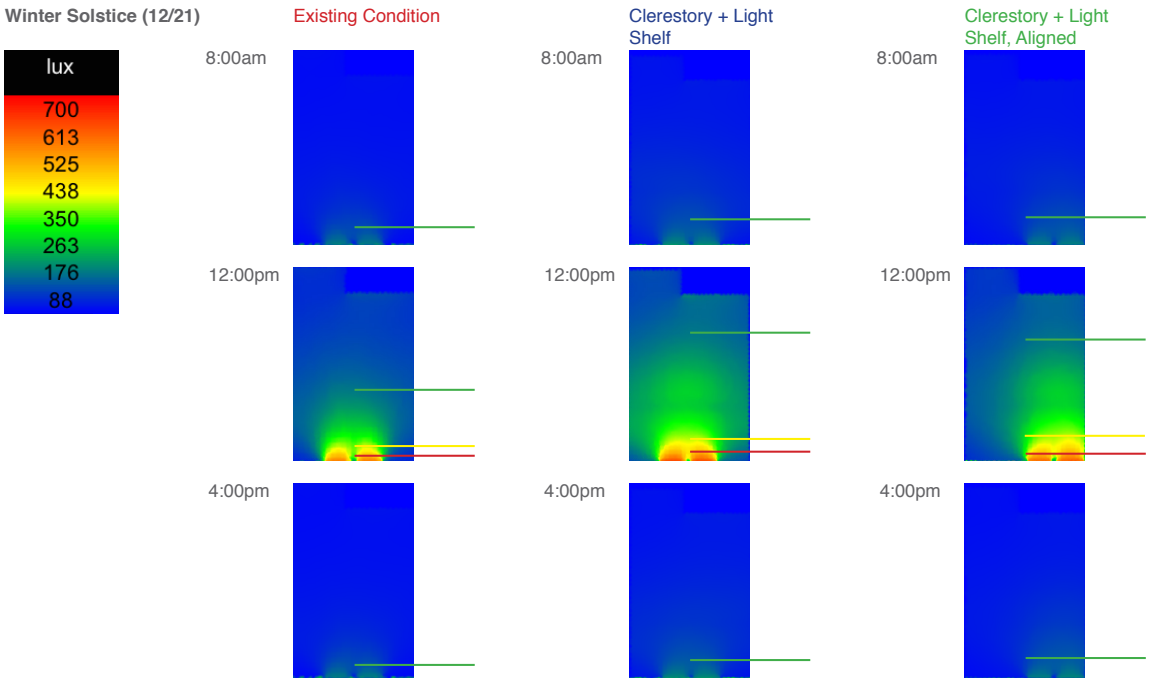
APPENDIX C: DAYLIGHT SIMULATIONS

Daylight simulations for “French Door room” design and recommendation variations:

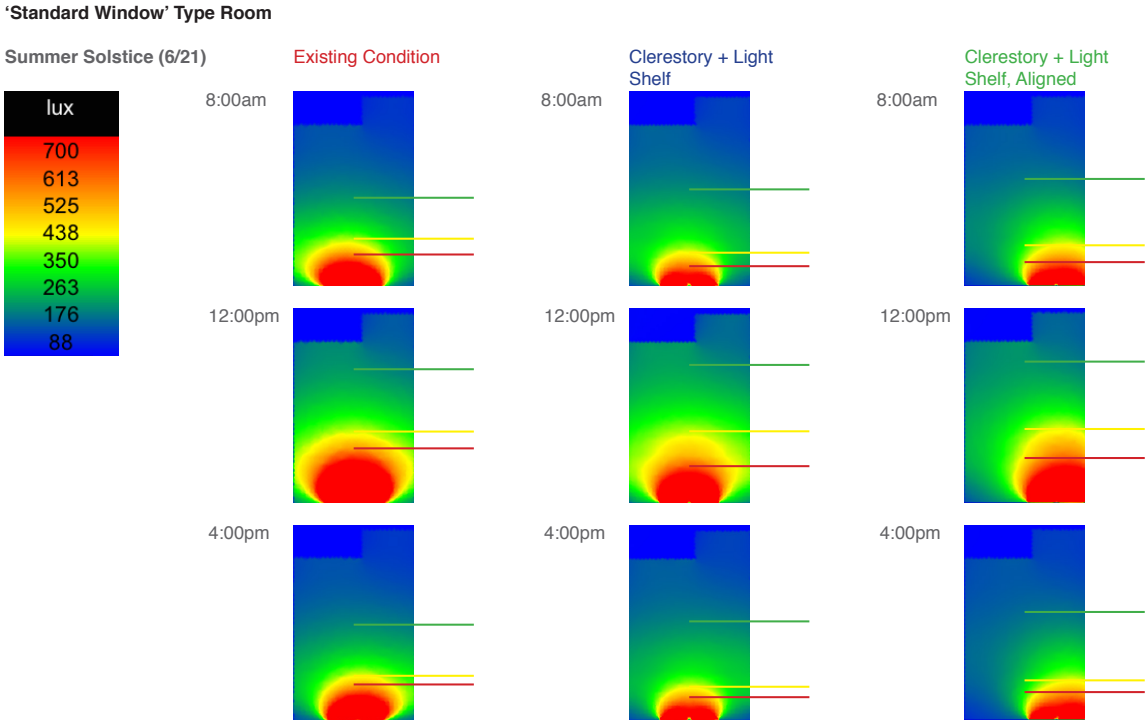


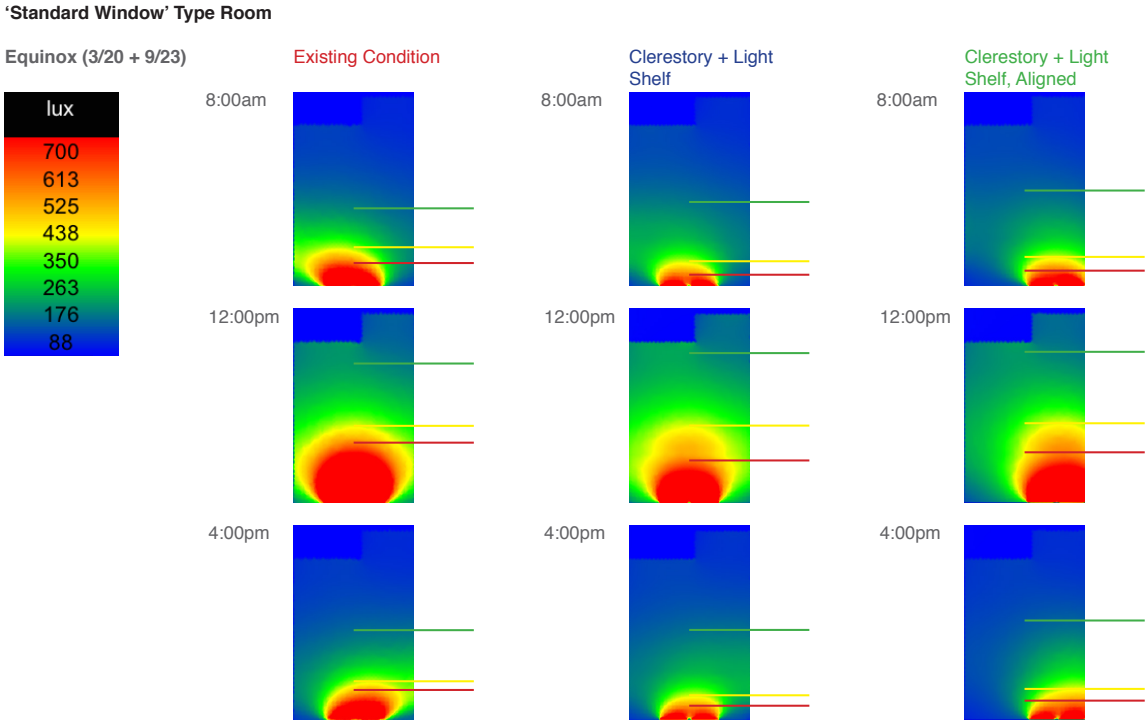


‘French Door’ Type Room



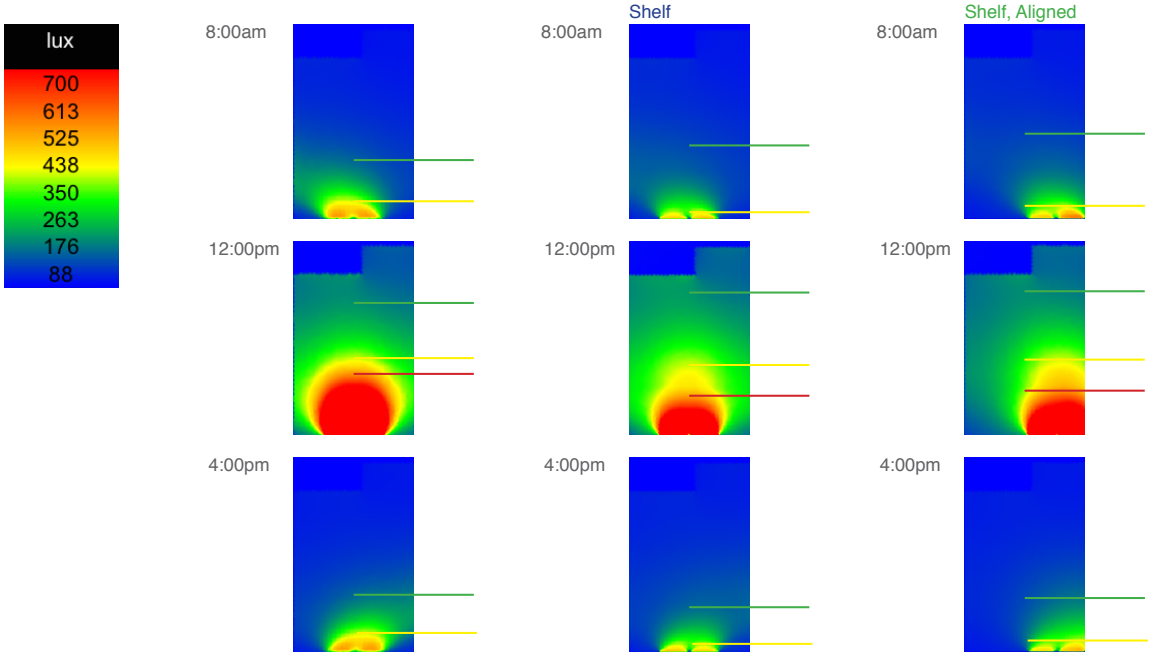
Daylight simulations for “Standard Window room” design and recommendation variations:





‘Standard Window’ Type Room

Winter Solstice (12/21)



BIBLIOGRAPHY

Annear, M., Keeling, S., Wilkinson, T., Cushman, G., Gidlow, B., & Hopkins, H. (2012). Environmental influences on healthy and active ageing: A systematic review. *Ageing and Society,34*(4), 590-622. doi:10.1017/s0144686x1200116x

Beute, F., & DeKort, Y. (2014). Enlightened thoughts : Associations with daylight versus electric light, preference formation, and recovery from stress. *Experiencing Light 2014: International Conference on the Effects of Light on Wellbeing*.

Borisuit, A., Linhart, F., Scartezzini, J., & Münch, M. (2014). Effects of realistic office daylighting and electric lighting conditions on visual comfort, alertness and mood. *Lighting Research & Technology,47*(2), 192-209. doi:10.1177/1477153514531518

Boubekri, M., Cheung, I. N., Reid, K. J., Wang, C., & Zee, P. C. (2014). Impact of Windows and Daylight Exposure on Overall Health and Sleep Quality of Office Workers: A Case-Control Pilot Study. *Journal of Clinical Sleep Medicine*. doi:10.5664/jcsm.3780

Burton, E. J., Mitchell, L., & Stride, C. B. (2011). Good places for ageing in place: Development of objective built environment measures for investigating links with older peoples wellbeing. *BMC Public Health,11*(1). doi:10.1186/1471-2458-11-839

Figueiro, M., Higgins, P., Hornick, T., Epur, A., & Rea, M. (2012). Field measurements of circadian light exposures, activity levels and degrees of circadian entrainment in healthy older adults and in persons with Alzheimers disease. *Alzheimers & Dementia,8*(4). doi:10.1016/j.jalz.2012.05.1185

Figueiro, M. G., Steverson, B., Heerwagen, J. H., & Rea, M. S. (2015). Daylight in office buildings-Impact of design on personal light exposures, sleep, and mood. *28th International Commission on Illumination*.

Figueiro, M. G., Steverson, B., Heerwagen, J., Kampschroer, K., Hunter, C. M., Gonzales, K., . . . Rea, M. S. (2017). The impact of daytime light exposures on sleep and mood in office workers. *Sleep Health,3*(3), 204-215. doi:10.1016/j.sleh.2017.03.005

Figueiro, M., & Rea, M. (2014). Office lighting and personal light exposures in two seasons: Impact on sleep and mood. *Lighting Research & Technology,48*(3), 352-364. doi:10.1177/1477153514564098

Garin, N., Olaya, B., Miret, M., Ayuso-Mateos, J. L., Power, M., Bucciarelli, P., & Haro, J. M. (2014). Built Environment and Elderly Population Health: A Comprehensive Literature Review. *Clinical Practice & Epidemiology in Mental Health,10*(1), 103-115. doi:10.2174/1745017901410010103

Harb, F., Hidalgo, M. P., & Martau, B. (2014). Lack of exposure to natural light in the workspace is associated with physiological, sleep and depressive symptoms. *Chronobiology International,32*(3), 368-375. doi:10.3109/07420528.2014.982757

Higuchi, M., Tanabe, S., Nishihara, N., Ito, K., Nagareda, A., Ito, T., . . . Mase, R. (2012). Indoor Environment and Productivity in a Green Building. *10th International Conference on Healthy Buildings 2012*.

Horr, Y. A., Arif, M., Kaushik, A., Mazroei, A., Katafygiotou, M., & Elsarrag, E. (2016). Occupant productivity and office indoor environment quality: A review of the literature. *Building and Environment,105*, 369-389. doi:10.1016/j.buildenv.2016.06.001

Horr, Y. A., Arif, M., Katafygiotou, M., Mazroei, A., Kaushik, A., & Elsarrag, E. (2016). Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature. *International Journal of Sustainable Built Environment,5*(1), 1-11. doi:10.1016/j.ijsbe.2016.03.006

Jones-Rounds, M. L., Evans, G. W., & Braubach, M. (2013). The interactive effects of housing and neighbourhood quality on psychological well-being. *Journal of Epidemiology and Community Health,68*(2), 171-175. doi:10.1136/jech-2013-202431

Kamarulzaman, N., Saleh, A., Hashim, S., Hashim, H., & Abdul-Ghani, A. (2011). An Overview of the Influence of Physical Office Environments Towards Employee. *Procedia Engineering,20*, 262-268. doi:10.1016/j.proeng.2011.11.164

Liang, H., Chen, C., Hwang, R., Shih, W., Lo, S., & Liao, H. (2014). Satisfaction of occupants toward indoor environment quality of certified green office buildings in Taiwan. *Building and Environment,72*, 232-242. doi:10.1016/j.buildenv.2013.11.007

Macnaughton, P., Spengler, J., Vallarino, J., Santanam, S., Satish, U., & Allen, J. (2016). Environmental perceptions and health before and after relocation to a green building. *Building and Environment,104*, 138-144. doi:10.1016/j.buildenv.2016.05.011

Macnaughton, P., Satish, U., Laurent, J. G., Flanigan, S., Vallarino, J., Coull, B., . . . Allen, J. G. (2017). The impact of working in a green certified building on cognitive function and health. *Building and Environment,114*, 178-186. doi:10.1016/j.buildenv.2016.11.041

Mulville, M., Callaghan, N., & Isaac, D. (2016). The impact of the ambient environment and building configuration on occupant productivity in open-plan commercial offices. *Journal of Corporate Real Estate,18*(3), 180-193. doi:10.1108/jcre-11-2015-0038

Sahin, L., Wood, B. M., Plitnick, B., & Figueiro, M. G. (2014). Daytime light exposure: Effects on biomarkers, measures of alertness, and performance. *Behavioural Brain Research,274*, 176-185. doi:10.1016/j.bbr.2014.08.017

Singh, A., Syal, M., Grady, S. C., & Korkmaz, S. (2010). Effects of Green Buildings on Employee Health and Productivity. *American Journal of Public Health,100*(9), 1665-1668. doi:10.2105/ajph.2009.180687

Streets ahead? The role of the built environment in healthy ageing. (2012). *Perspectives in Public Health,132*(4), 161-162. doi:10.1177/1757913912449570

Thayer, J. F., Verkuil, B., Brosschotj, J. F., Kevin, K., West, A., Sterling, C., . . . Sternberg, E. M. (2010). Effects of the physical work environment on physiological measures of stress. *European Journal of Cardiovascular Prevention & Rehabilitation,17*(4), 431-439. doi:10.1097/hjr.0b013e328336923a

Trecartin, S. M., & Cummings, S. M. (2018). Systematic review of the physical home environment and the relationship to psychological well-being among community-dwelling older adults. *Journal of Gerontological Social Work,61*(5), 567-582. doi:10.1080/01634372.2018.1463339

Turner, P. L., Someren, E. J., & Mainster, M. A. (2010). The role of environmental light in sleep and health: Effects of ocular aging and cataract surgery. *Sleep Medicine Reviews,14*(4), 269-280. doi:10.1016/j.smrv.2009.11.002

Villanueva, K., Pereira, G., Knuiman, M., Bull, F., Wood, L., Christian, H., . . . Giles-Corti, B. (2013). The impact of the built environment on health across the life course: Design of a cross-sectional data linkage study. *BMJ Open,3*(1). doi:10.1136/bmjopen-2012-002482